www.bsc.es

REPSOL

Barcelona Supercomputing Center
Centro Nacional de Supercomputación

HPC CHALLENGES IN THE OIL INDUSTRY, PART 2: BARCELONA SUBSURFACE IMAGING TOOLS (BSIT)

February 2016

What is BSIT?

A set of software frameworks and support tools for building geophysical imaging software

Geophysical Software Solution for the Industry

Our product is required to have...

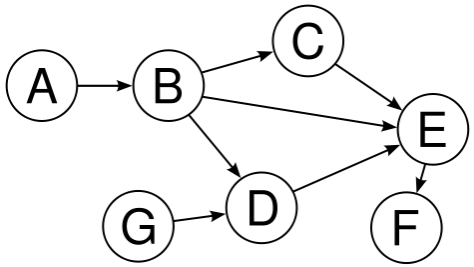
...accuracy

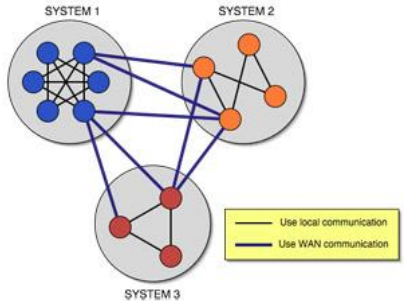
...reliability

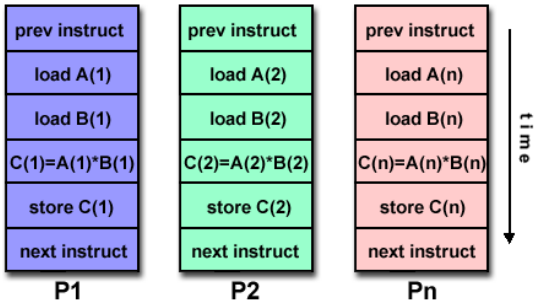
...efficiency

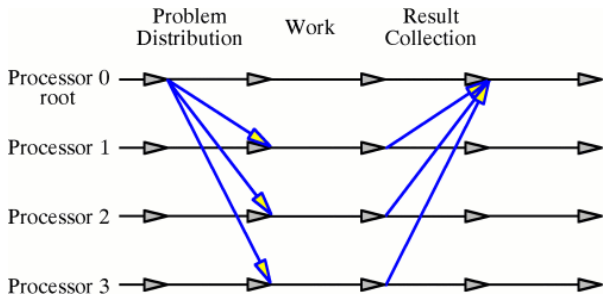
Parallelism Needs in Geophysics

- **4 levels of parallellism**
  - **DAG**: embarrassingly parallel.
  - **MPI**: message passing between tasks
  - **OpenMP**: shared memory between threads
  - **SIMD/SIMT**: vectorial code.

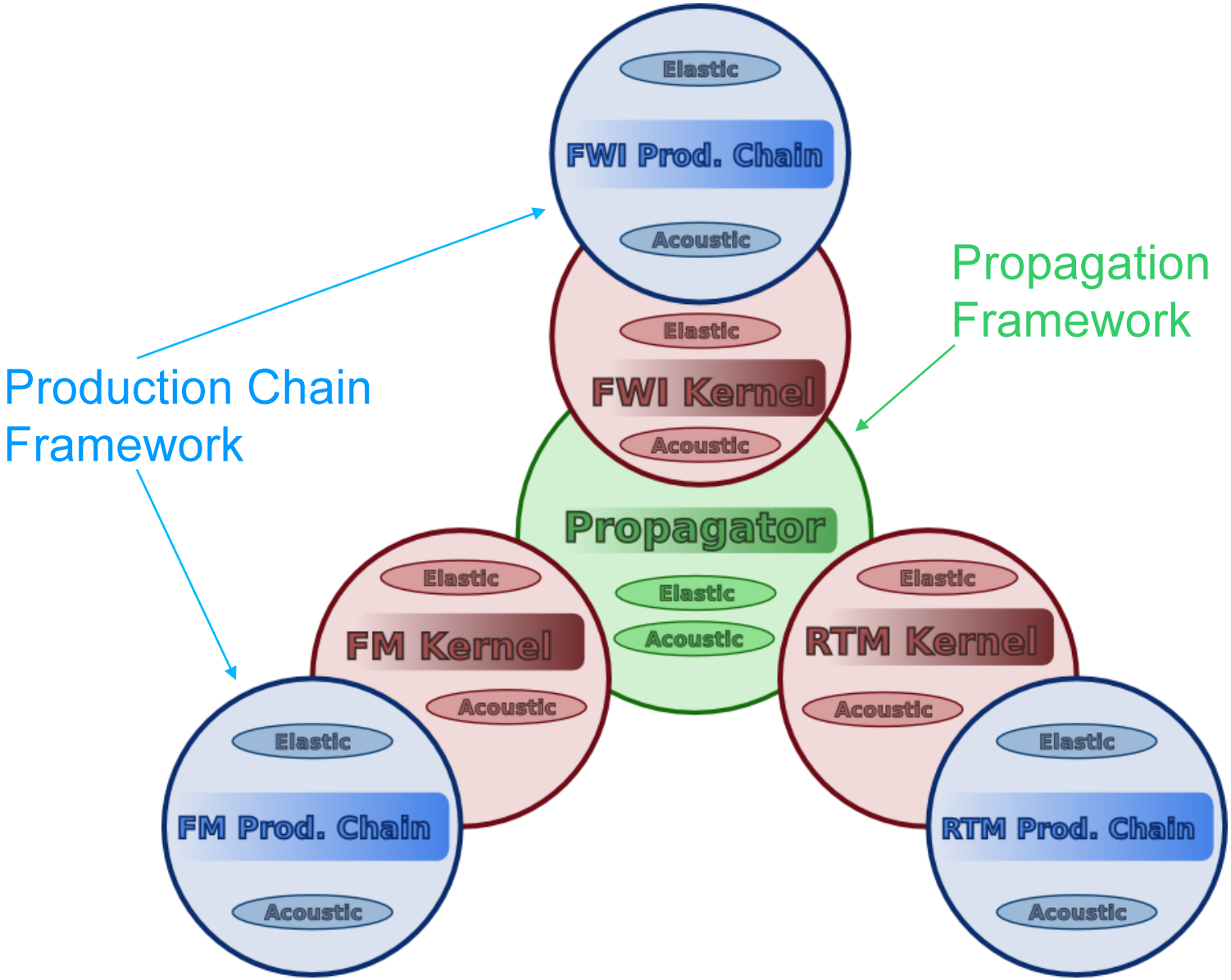




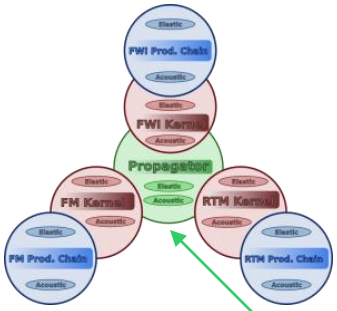




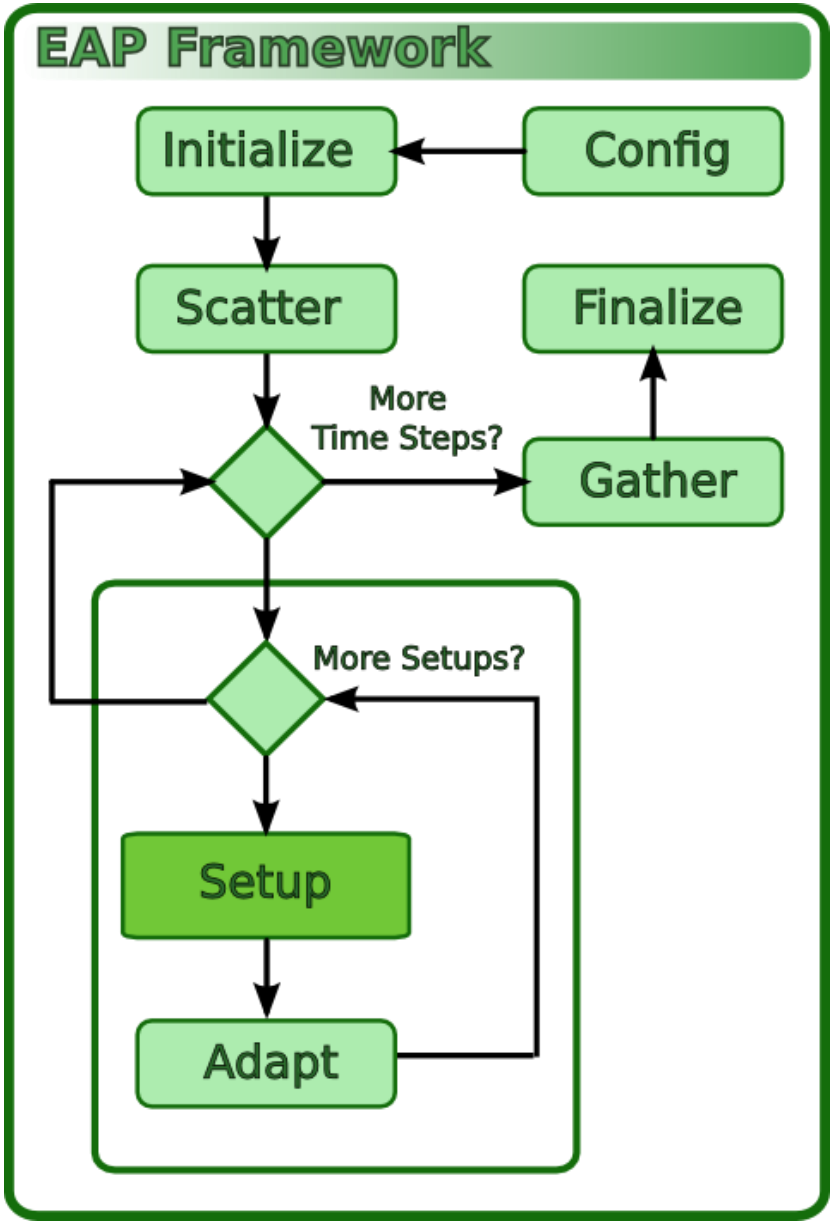
BSIT Frameworks



Environment for Assesing Performance (EAP)

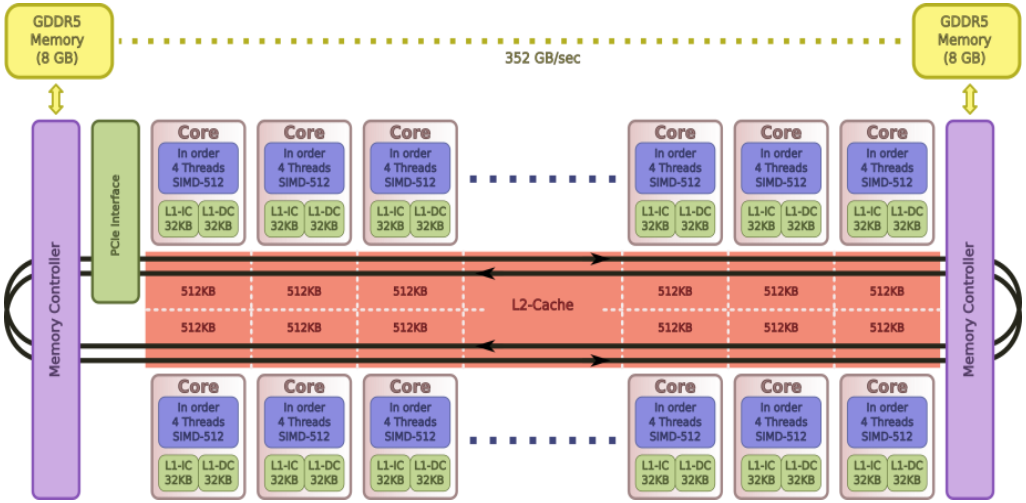


Propagation Framework

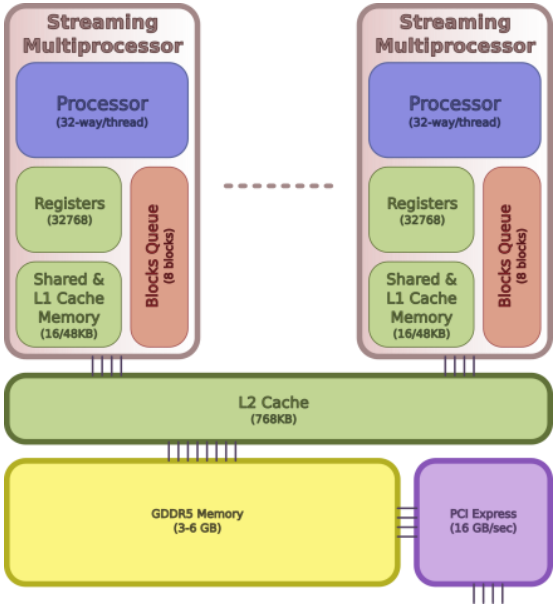


Supported Architectures

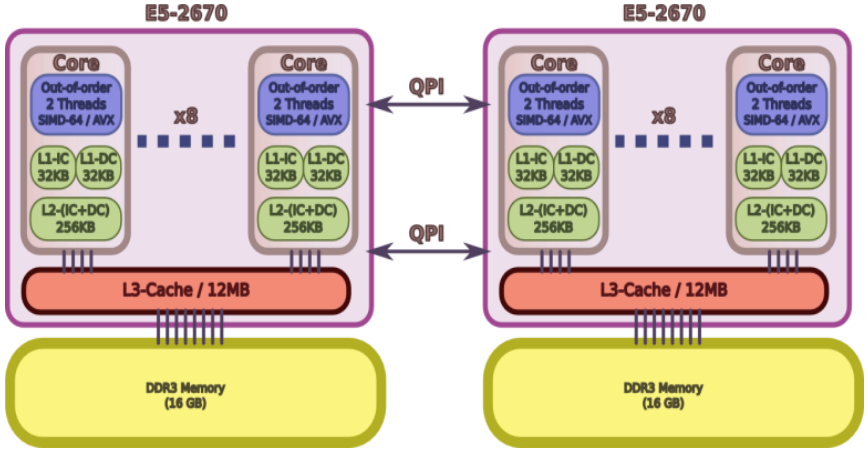
Intel's Xeon Phi



Nvidia's Fermi/Kepler

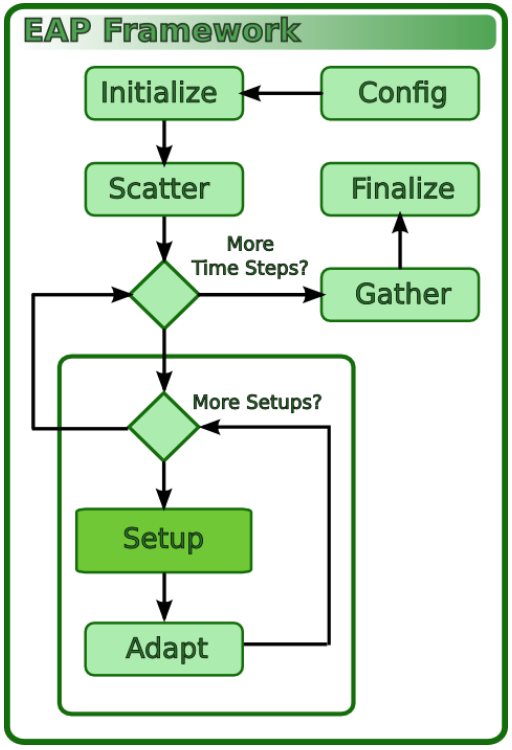


Intel's Sandy Bridge

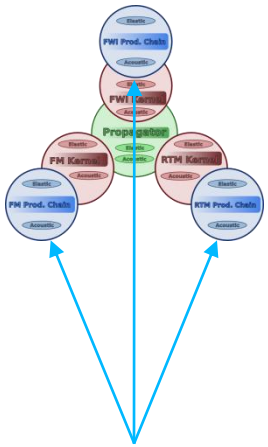


EAP main contributions

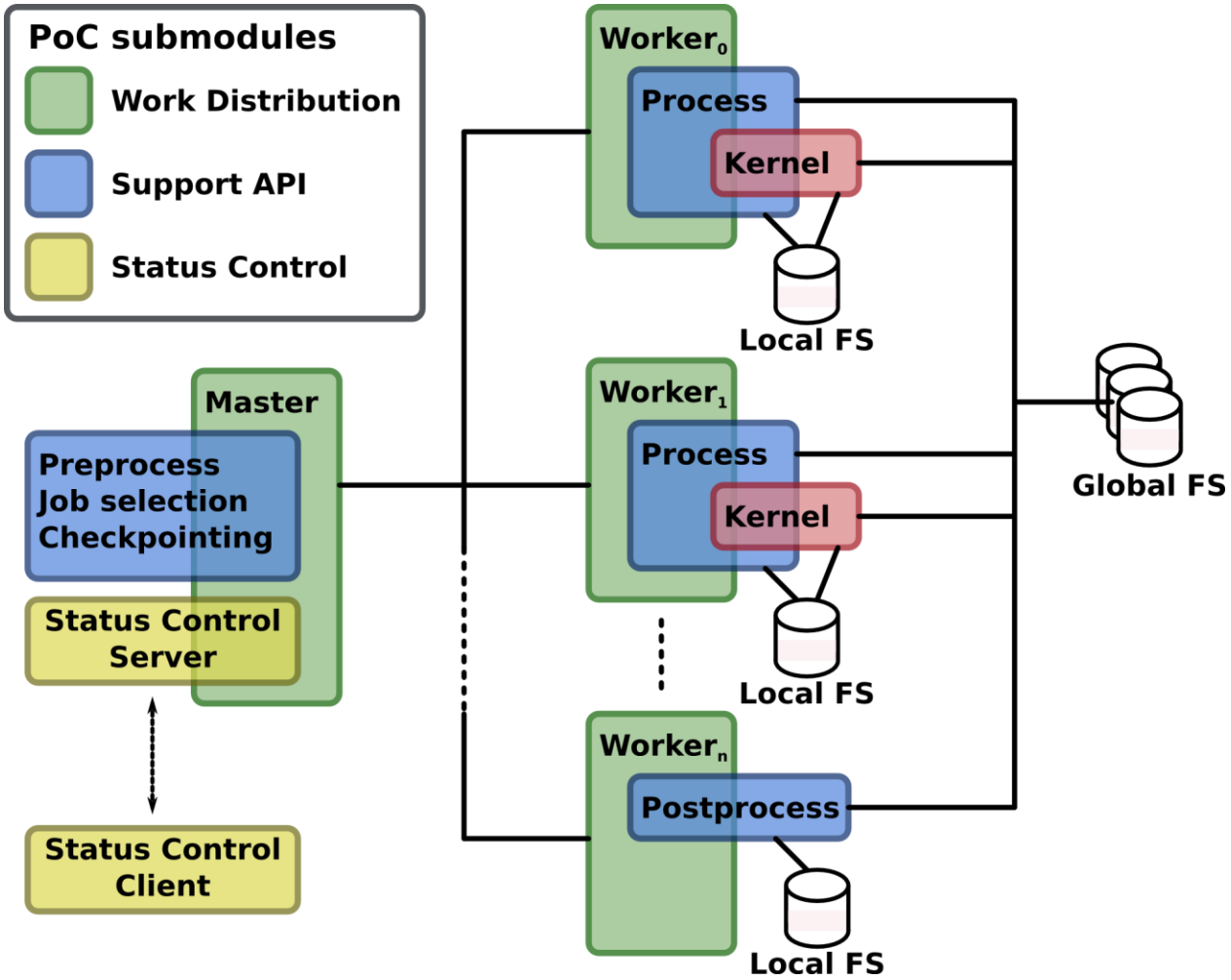
- **Focus on your problem and not in the HPC**
  - You already have domain decomposition and parallel I/O.
- **Easier to port to novel architectures**
  - Only some specific pieces must be ported, and they are well defined and encapsulated.
- **Can produce different systems with minimal effort**
  - Code reusing is easier due to framework modularity.



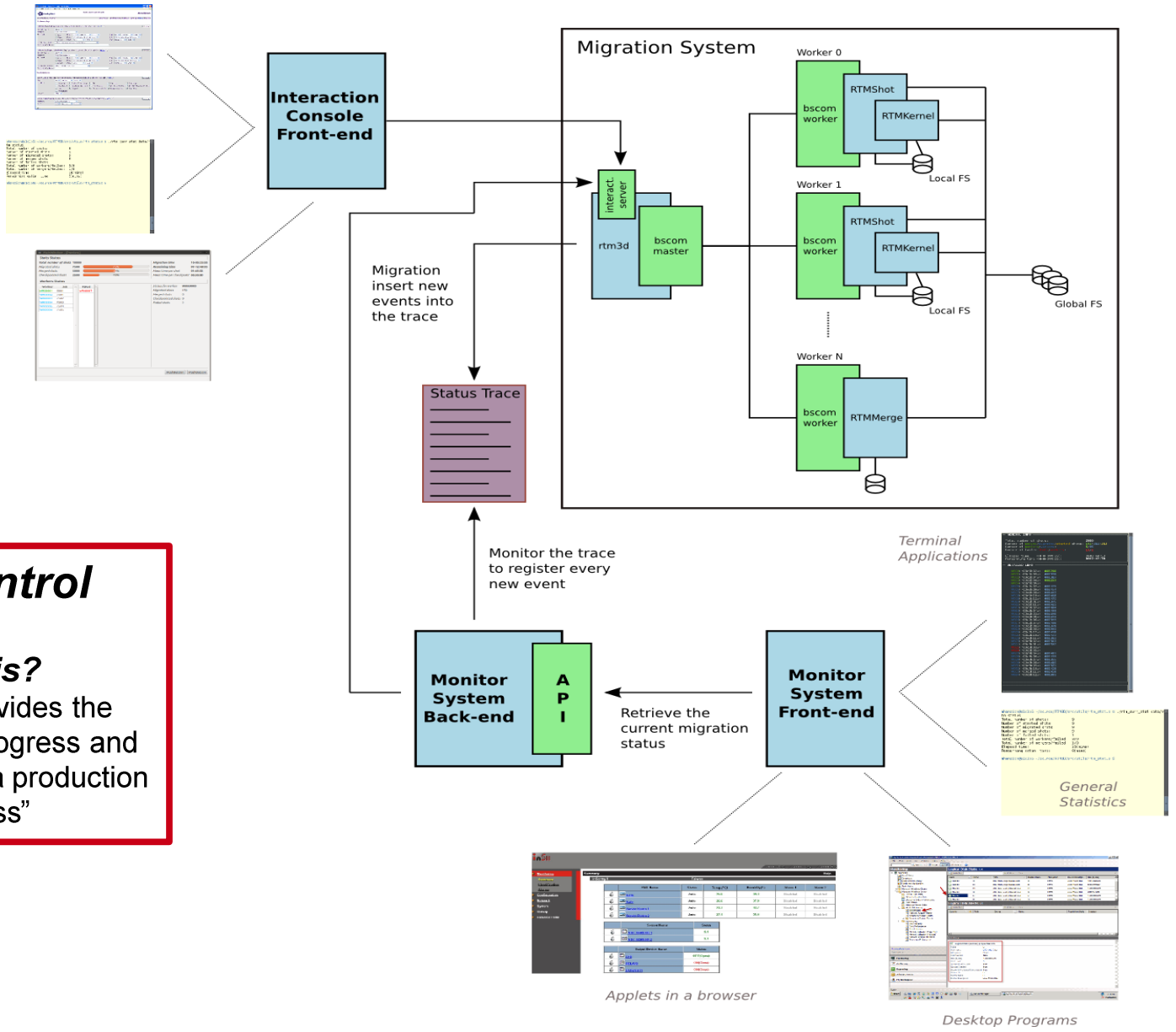
Environment for Assesing Confidence (EAC)



Production Chain Framework



EAC Status Control



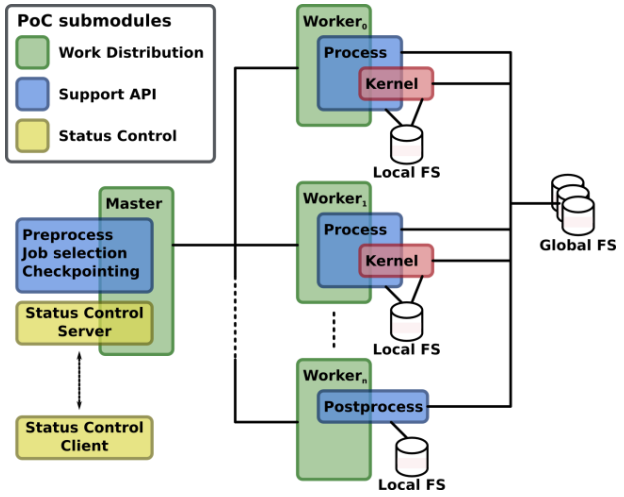
Status Control

What is this?

"A system that provides the means to monitor progress and update the status of a production chain process"

EAC Main Contributions

- **Focus on your problem and not in the Fault Tolerance**
  - You already have data corruption and worker failure management included.
- **Easier to include a postprocess of your data**
  - Capability for postprocessing and merging of partial results already included.
- **Large support API for Geophysical data**
  - Management for volumetric data, signal traces, wavelets, databases, etc, already in place and can be easily extended with new functionality as needed.

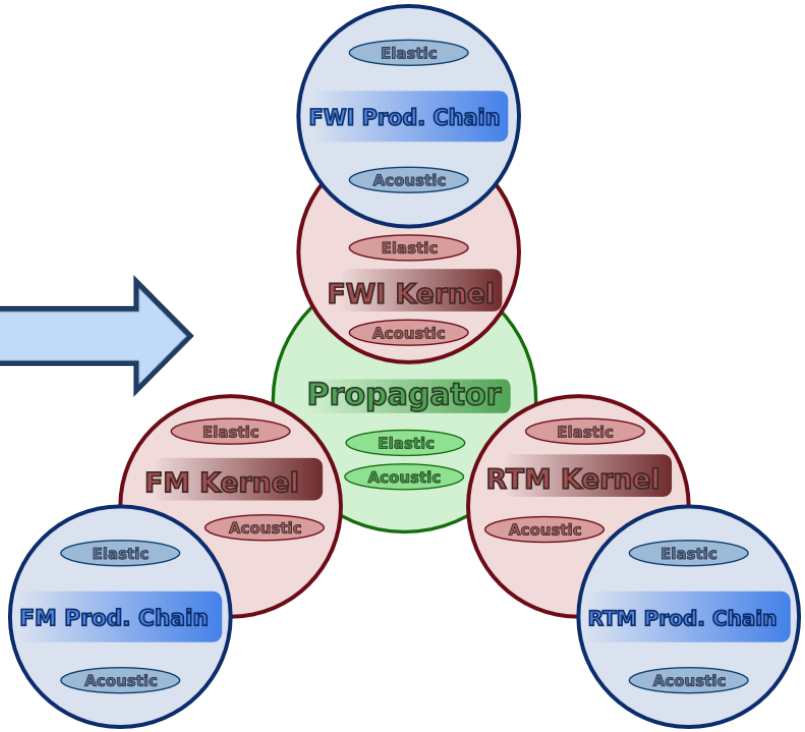


BSIT… a bit of history

BSIT-I
(Kaleidoscope)

Acoustic RTM on
Cell/B.E.

BSIT-II
(Repsol-BSC Research Center)



BSIT-I in Numbers (Kaleidoscope)

acoustic.2d.cell.rtm
acoustic.3d.cell.rtm

2 Kernels
RTM
Acoustic

rtm_acoustic
rtm_acoustic_kernel.sh
rtm_acoustic_post
rtm_acoustic_proc
rtm_chkp
RTMkernel.sh

6 Production Chain Binaries
RTM
Acoustic

General
Lines of Code: > **40K**
Doc Lines: >**10K**
Releases: **~2**
Local version: **~200**
People: **5**

Supported Hardware:
Cell/B.E.

Parallel Paradigms
MPI
Cell/B.E. SDK

4 years of development

BSIT-II in Numbers (RBRC)

acoustic.2d.cuda.rtm
acoustic.2d.gp.fm
acoustic.2d.gp.fwi
acoustic.2d.gp.rtm
acoustic.3d.cuda.rtm
acoustic.3d.gp.fm
acoustic.3d.gp.fwi
acoustic.3d.gp.rtm
elastic.2d.fsg.cuda.fm
elastic.2d.fsg.gp.fm
elastic.2d.fsg.gp.fwi
elastic.2d.fsg.gp.rtm
elastic.2d.fsg.hti.cuda.fm
elastic.2d.fsg.hti.gp.fm
elastic.2d.fsg.hti.gp.rtm
elastic.2d.fsg.ort.cuda.fm
elastic.2d.fsg.ort.gp.fm
elastic.2d.fsg.ort.gp.rtm
elastic.2d.fsg.tti.cuda.fm
elastic.2d.fsg.tti.gp.fm
elastic.2d.fsg.vti.cuda.fm
elastic.2d.fsg.vti.gp.fm
elastic.2d.ssg.cuda.fm
elastic.2d.ssg.cuda.fwi
elastic.2d.ssg.gp.fm
elastic.2d.ssg.gp.fwi
elastic.2d.ssg.gp.rtm
elastic.2d.ssg.hti.cuda.fm
elastic.2d.ssg.hti.gp.fm
elastic.2d.ssg.hti.gp.rtm
elastic.2d.ssg.ort.cuda.fm
elastic.2d.ssg.ort.gp.fm
elastic.2d.ssg.ort.gp.rtm
elastic.2d.ssg.vti.cuda.fm
elastic.2d.ssg.vti.gp.fm
elastic.2d.ssg.vti.gp.rtm
elastic.2d.fsg.cuda.fm
elastic.2d.fsg.gp.fm
elastic.2d.fsg.gp.fwi
elastic.2d.fsg.gp.rtm
elastic.3d.fsg.gp.fm
elastic.3d.fsg.gp.fwi
elastic.3d.fsg.gp.rtm
elastic.3d.fsg.hti.cuda.fm
elastic.3d.fsg.hti.gp.fm
elastic.3d.fsg.hti.gp.rtm
elastic.3d.fsg.ort.cuda.fm
elastic.3d.fsg.ort.gp.fm
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elastic.3d.ssg.gp.fm
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elastic.3d.ssg.gp.rtm
elastic.3d.ssg.hti.cuda.fm
elastic.3d.ssg.hti.gp.fm
elastic.3d.ssg.hti.gp.rtm
elastic.3d.ssg.ort.cuda.fm
elastic.3d.ssg.ort.gp.fm
elastic.3d.ssg.ort.gp.rtm
elastic.3d.ssg.vti.cuda.fm
elastic.3d.ssg.vti.gp.fm
elastic.3d.ssg.vti.gp.rtm
em.iso.gp.fm
em.vti.gp.fm

68 Kernels
FM/RTM/FWI
Acoustic/Elastic/CSEM

36 Production Chain Binaries
FM/RTM/FWI
Acoustic/Elastic/CSEM

emigrad_chkp
EMIGradkernel.sh
emigrad_post
emigrad_proc
emigrad_sche
emimain
emitest_chkp
emitest_post
emitest_proc
emitest_sche
fwigrad_chkp
fwigradinit_proc
fwigradinit_sche
FWIGradkernel.sh
fwigradloop
fwigrad_post
fwigrad_proc
fwigrad_sche
fwimain
fwitest_chkp
fwitest_post
fwitest_proc
fwitest_sche
fm_freq_post
fm_freq_proc
fm_freq_sche
FMkernel.sh
fm_time_chkp
fm_time_post
fm_time_proc
fm_time_sche
rtm_chkp
RTMkernel.sh
rtm_post
rtm_proc
rtm_sche

libeap.a
libeapdacoustic2d.a
libeapdacoustic2dgp.a
libeapdacoustic2dgpfm.a
libeapdacoustic2dgpfwi.a
libeapdacoustic3d.a
libeapdacoustic3dgp.a
libeapdacoustic3dgpfm.a
libeapdacoustic3dgpfwi.a
libeapdacousticgprtm.a
libeapdelastic2dfsgcommon.a
libeapdelastic2dfsggp.a
libeapdelastic2dfsghticommon.a
libeapdelastic2dfsghtigp.a
libeapdelastic2dfsgortcommon.a
libeapdelastic2dfsgortgp.a
libeapdelastic2dfsgtticommon.a
libeapdelastic2dfsgttigp.a
libeapdelastic2dfsgvticommon.a
libeapdelastic2dfsgvtigp.a
libeapdelastic2dssgcommon.a
libeapdelastic2dssggp.a
libeapdelastic2dssghticommon.a
libeapdelastic2dssghtigp.a
libeapdelastic2dssgortcommon.a
libeapdelastic2dssgortgp.a
libeapdelastic2dssgvticommon.a
libeapdelastic2dssgvtigp.a
libeapdelastic3dfsgcommon.a
libeapdelastic3dfsggp.a
libeapdelastic3dfsghticommon.a
libeapdelastic3dfsghtigp.a
libeapdelastic3dfsgortcommon.a
libeapdelastic3dfsgortgp.a
libeapdelastic3dfsgtticommon.a
libeapdelastic3dfsgttigp.a
libeapdelastic3dfsgvticommon.a
libeapdelastic3dfsgvtigp.a
libeapdelastic3dssgcommon.a
libeapdelastic3dssggp.a
libeapdelastic3dssghticommon.a
libeapdelastic3dssghtigp.a
libeapdelastic3dssgortcommon.a
libeapdelastic3dssgortgp.a
libeapdelastic3dssgvticommon.a
libeapdelastic3dssgvtigp.a
libeapdelastic.a
libeapdelasticgpfm.a
libeapdelasticgpfwi.a
libeapdelasticgprtm.a
libeapdem.a
libeapdemfm.a
libeapdeminv.a
libeapdemiso.a
libeapdemvti.a
libeaps.a
libeapsa.a
libeapsagp_c.a
libeapsagp_d.a
libeapsagp_s.a
libeapsagp_z.a
libeapsgp.a
libeapss.a
libeapsscg.a
libeapsssqmr.a

65 Propagation Libraries
Framework
FM/RTM/FWI
Acoustic/Elastic/CSEM

General
Lines of Code: **> 200K**
Doc Lines: **>100K**
Releases: **~12**
Local version: **~3500**
People: **10**

Supported Hardware:
General Purpose
GPUs
Xeon Phi's
Blue Gene / Q
Tegra

Parallel Paradigms
MPI
OpenMP
SSE/AVK
CUDA

Only 4 years of development!!!

BSIT Development Philosophy

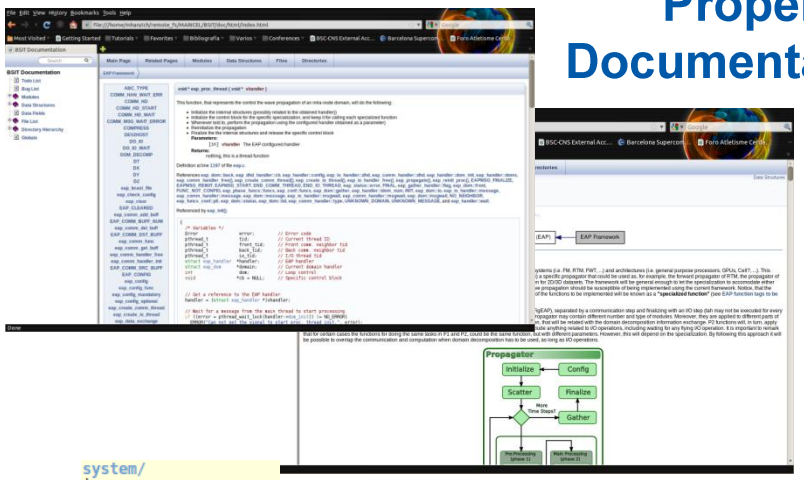
THINK FIRST!!!

BSIT Development Philosophy

Compilation System

```
File  Edit  View  Search  Terminal  Help
Creating library: libsdbmng.a                                    [OK]
Copying header:   sdbmng.h                                       [OK]
Creating bin: sdbextract                                         [OK]
Creating bin: sdbshotpos                                         [OK]
Creating bin: sdbposshot                                         [OK]
Creating bin: sdbshotcdp                                         [OK]
Creating bin: sdbwritecoords                                     [OK]

------ SDBGEN ------------------------------------------------------------
Creating bin: sdbgen                                             [OK]
Creating bin: sdbgen_mpi                                         [OK]
Creating bin: bboxgen_mpi                                        [OK]
Creating lnk: sdbgen.sh (script)                                 [OK]
Creating lnk: sdbgen.slurm (script)                              [OK]

------ VOLMNG ------------------------------------------------------------
Compiling object: volmng.o                                       [OK]
Creating library: libvolextract.a                                [OK]
Copying header:   volmng.h                                       [OK]
Compiling object: vol_extract.o                                  [OK]
Linking binary:   vol_extract                                    [OK]

------------------------------------------------------------------------

************************************************************************
****************************** MAIN/EAP ********************************
************************************************************************
------ HOST (EAP Framework) ----------------------------------------------
Creating obj: eap.o                                              [OK]
Creating obj: eap_comm.o                                         [OK]
Creating obj: eap_dhd.o                                          [OK]
Creating obj: eap_io.o                                           [OK]
Creating obj: eap_template.o                                     [OK]
Creating lib: libeap.a                                           [OK]
Creating links to public headers...                              [OK]

------ DUMMY (EAP Device) ------------------------------------------------
Creating obj: eapd_abc.o                                         [OK]
Creating obj: eapd_comm.o                                        [OK]
Creating obj: eapd_comp.o                                        [OK]
Creating obj: eapd_dd.o                                          [OK]
Creating obj: eapd_free.o                                        [OK]
Creating obj: eapd_img.o                                         [OK]
Creating obj: eapd_init.o                                        [OK]
Creating obj: eapd_io.o                                          [OK]
Creating obj: eapd_main.o                                    [WARNING]

-------------------------- Command with warnings ---------------------------
mpicc -m64 -g -Wall -DMN -DSLURM -DUSE_MPI -I/opt/openmpi/ppc64/include -I/home/
Applications/mhanzich/BSIT/system/main/eap/include -I/home/Applications/mhanzich
/BSIT/system/support/common/include -I/home/Applications/mhanzich/BSIT/system/su
pport/logs/include -c -o /home/Applications/mhanzich/BSIT/system/main/eap/obj/ea
pd_main.o eapd_main.c
---------------------------------- Output ----------------------------------
eapd_main.c: In function 'eapd_dummy_main':
eapd_main.c:147: warning: unused variable 'z'
eapd_main.c:147: warning: unused variable 'y'
eapd_main.c:147: warning: unused variable 'x'
----------------------------------------------------------------------------

Creating obj: eapd_src.o                                         [OK]
Creating obj: eapd_wmd.o                                         [OK]
Creating lib: libeapdummy.a                                      [OK]
Creating links to public headers...                              [OK]
mhanzich@s1c1b2:~/BSIT $
```

Proper Documentation



Directory Structure

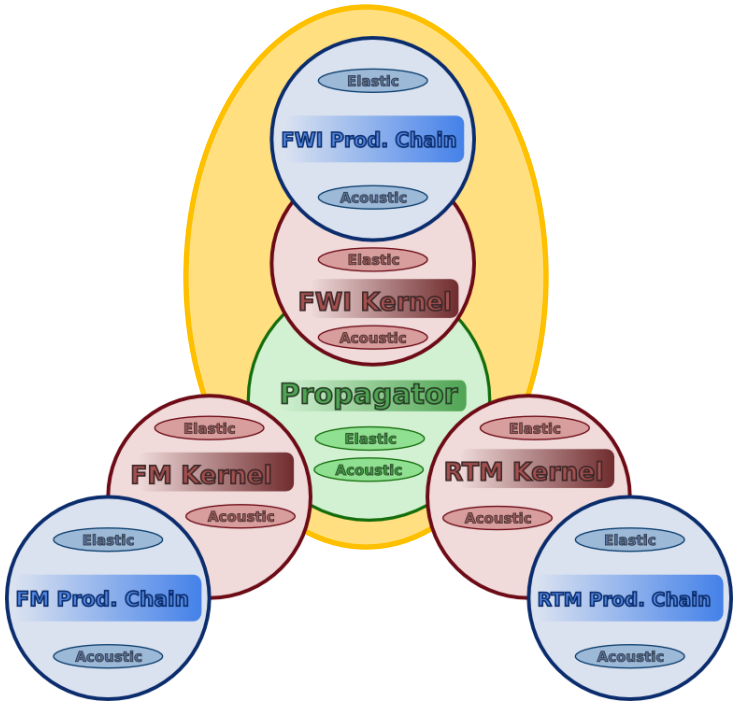
```
eap
├── bin
├── doc
│   └── images
├── examples
├── include
├── lib
├── obj
└── src
    ├── device
    │   ├── acou_rho
    │   │   ├── cuda
    │   │   │   └── fm
    │   │   └── gp
    │   │       └── fm
    │   ├── acoustic
    │   │   ├── arch
    │   │   │   ├── cell
    │   │   │   ├── cuda
    │   │   │   └── gp
    │   │   └── system
    │   │       ├── fm
    │   │       ├── fwi
    │   │       └── rtm
    │   ├── dummy
    │   │   ├── cuda
    │   │   └── gp
    │   └── elastic
    │       ├── arch
    │       │   ├── common
    │       │   ├── cuda
    │       │   └── gp
    │       └── system
    │           ├── fm
    │           └── rtm
    └── host
tests
├── data
├── results
└── scratch
```

```
system/
├── frontend
│   ├── gui
│   ├── tex
│   └── tty
├── main
│   ├── doc
│   ├── eac
│   ├── eap
│   ├── fm
│   ├── fwi
│   ├── kernel
│   ├── rtm
│   └── tomo
├── support
│   ├── atios
│   ├── bscdatatypes
│   ├── bscfft
│   ├── bscgeo
│   ├── bscom
│   ├── check_corrupt
│   ├── common
│   ├── doc
│   ├── endianness
│   ├── file
│   ├── filters
│   ├── jit
│   ├── logs
│   ├── monitoring
│   ├── optimization
│   ├── params
│   ├── segymng
│   └── trace
└── thirdparty
```

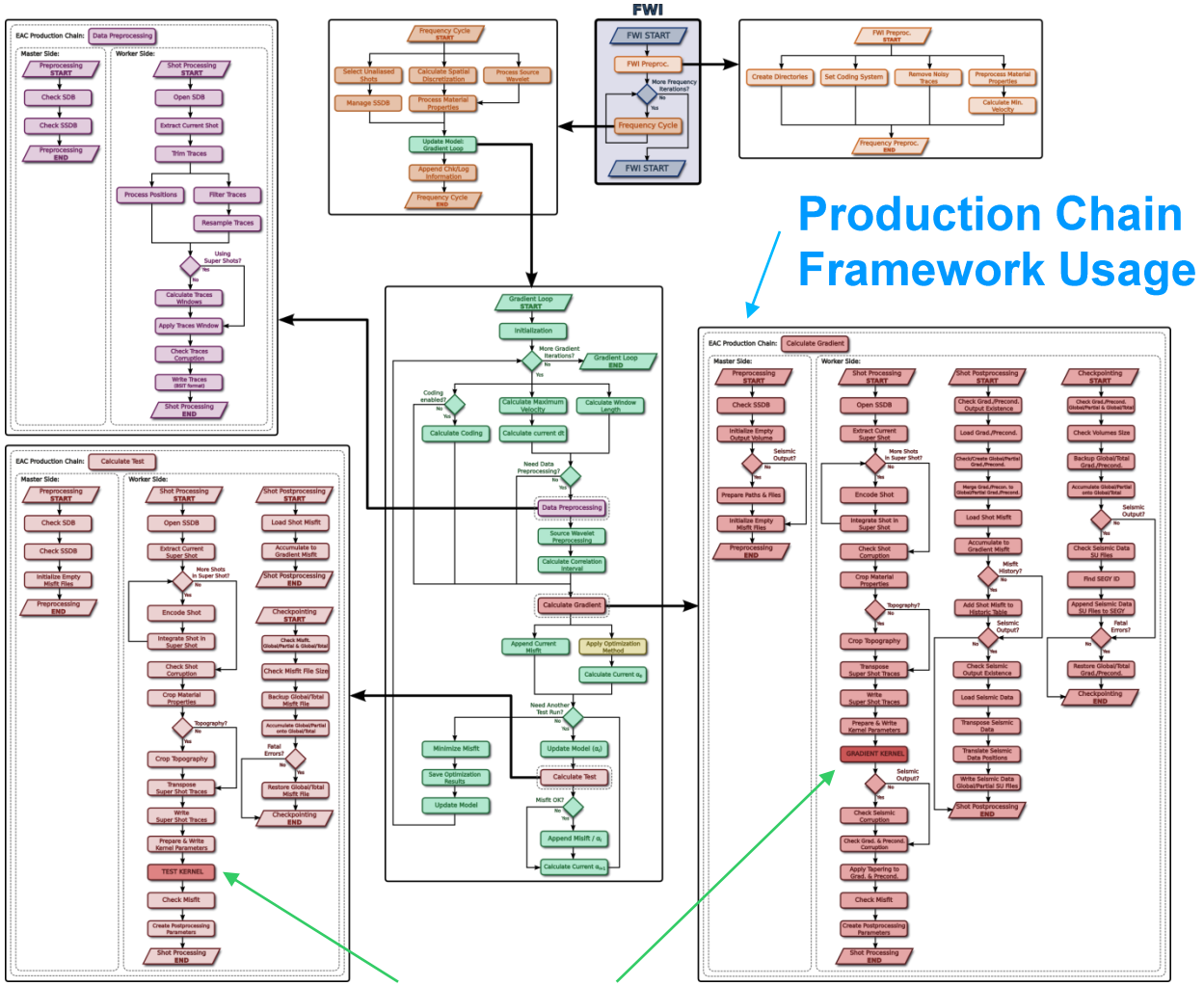
```
params/
├── doc
│   └── doc.doxy
├── include
│   └── grab_params.h
├── lib
│   ├── libparams.a
│   └── libparams_dyn.so
├── Makefile
├── obj
│   ├── grab_params.lo
│   └── grab_params.o
├── src
│   ├── grab_params.c
│   ├── grab_params.h
│   └── Makefile
└── tests
    ├── Makefile
    ├── test_params.c
    └── test_params_tree.c
```

BSIT-based Geophysical Systems

Full Waveform Inversion



Full Waveform Inversion on BSIT



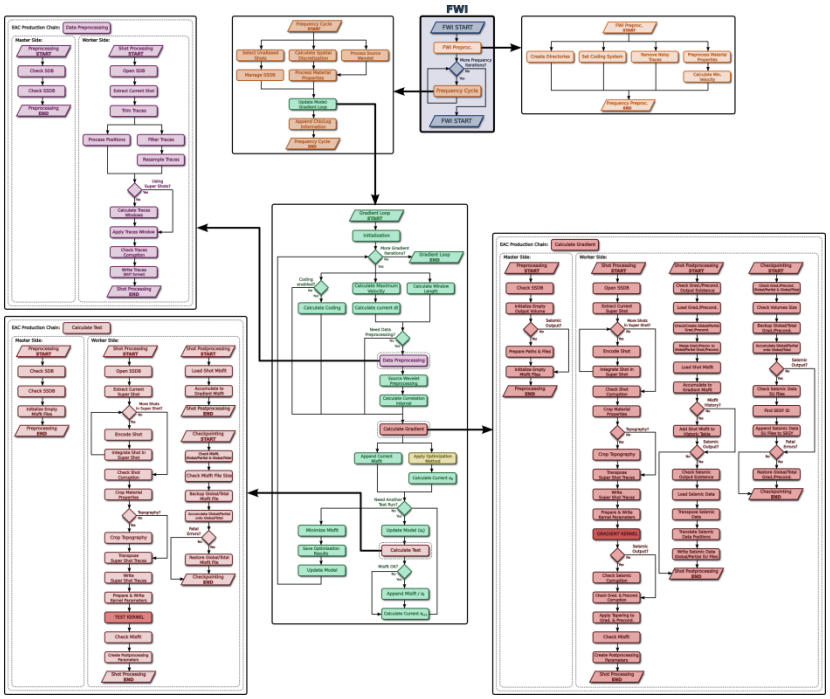
Production Chain Framework Usage

Production Chain Framework Usage

Propagation Framework Usage

Full Waveform Inversion on BSIT

- **You need to think a lot**
  - The drawing precedes the coding.
- **You need to invest a lot of time**
  - Two months / five-six persons to define this system design.
- **But once you have it, you'll advance fast!**
  - The development of a good design could be carried out in parallel, as you know the interactions.



Full Waveform Inversion on BSIT

- Time-domain solution
- In-house Preconditioner and Forward Modeling
- Multi-scale, multi-grid strategies: **ESSENTIAL FOR VIABILITY**
- Multi-shooting for data reduction: **ESSENTIAL FOR VIABILITY**
- Acoustic (2D and 3D) and Elastic FWI (2D nowadays)
- Flexible strategy implementation: **ESSENTIAL FOR VIABILITY**
- Minimalist data pre-processing: **ESSENTIAL IN INDUSTRIAL CONTEXT**

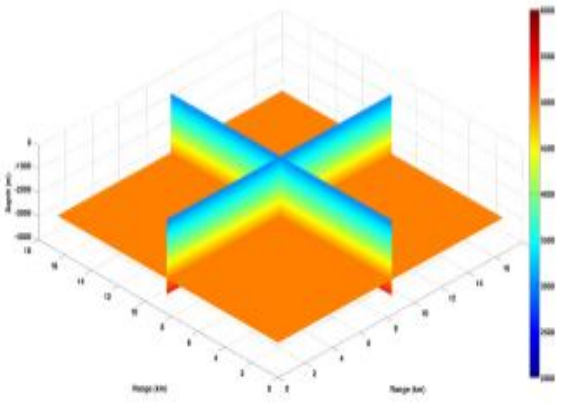
- **NEXT GENERATION MODEL BUILDER FOR RELIABLE RTM!**

Acoustic Full Waveform Inversion on BSIT

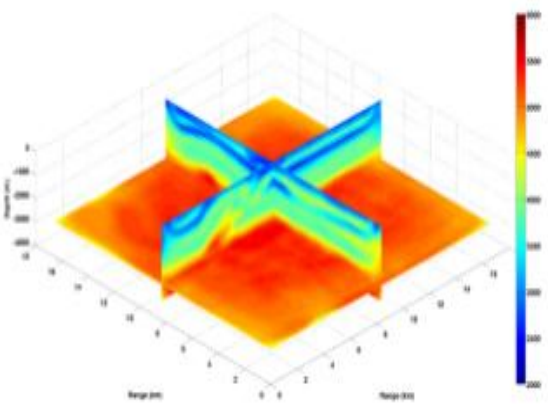
An Acoustic Test Case

- Time-domain solution
- 3D acoustic FWI
- 3249 sources, 3249 receivers
- 8s of simulation (250 Gb of data)
- Data compression 3249 → 56 supershots!
- 3 frequencies 25 iterations

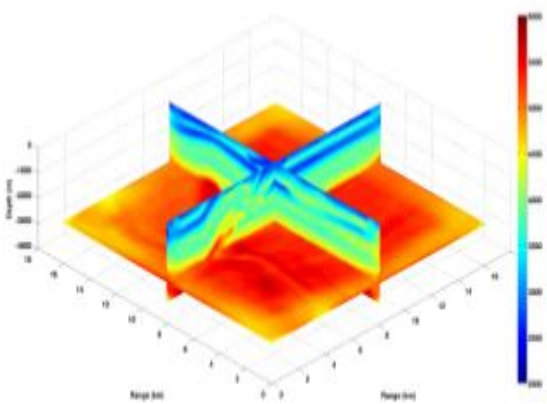
Acoustic Full Waveform Inversion on BSIT



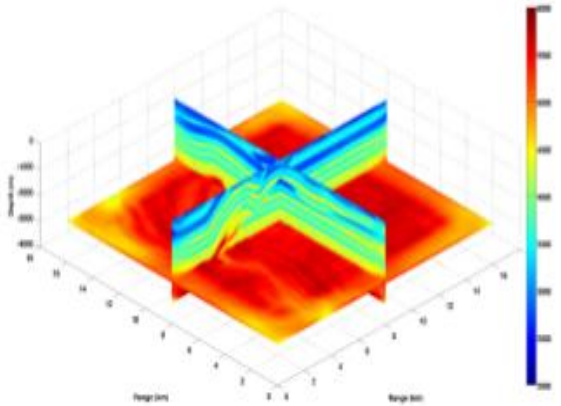
START



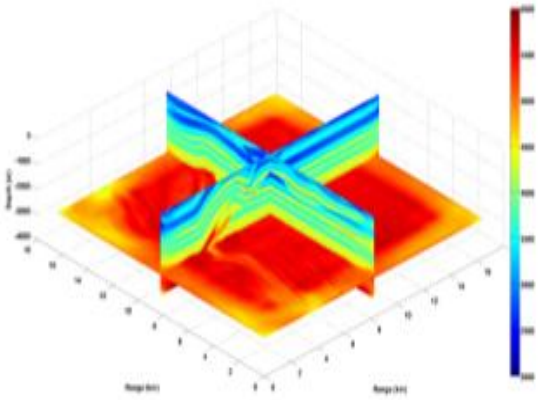
1 Hz



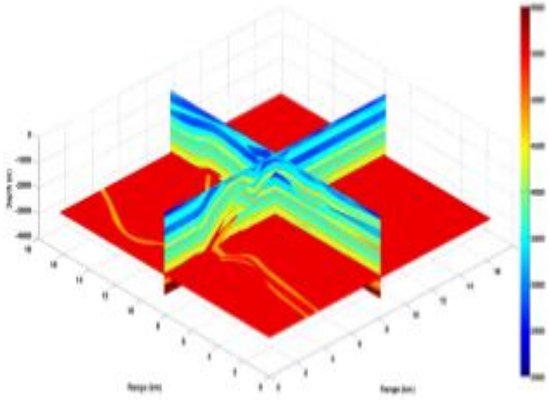
2 Hz



4 Hz

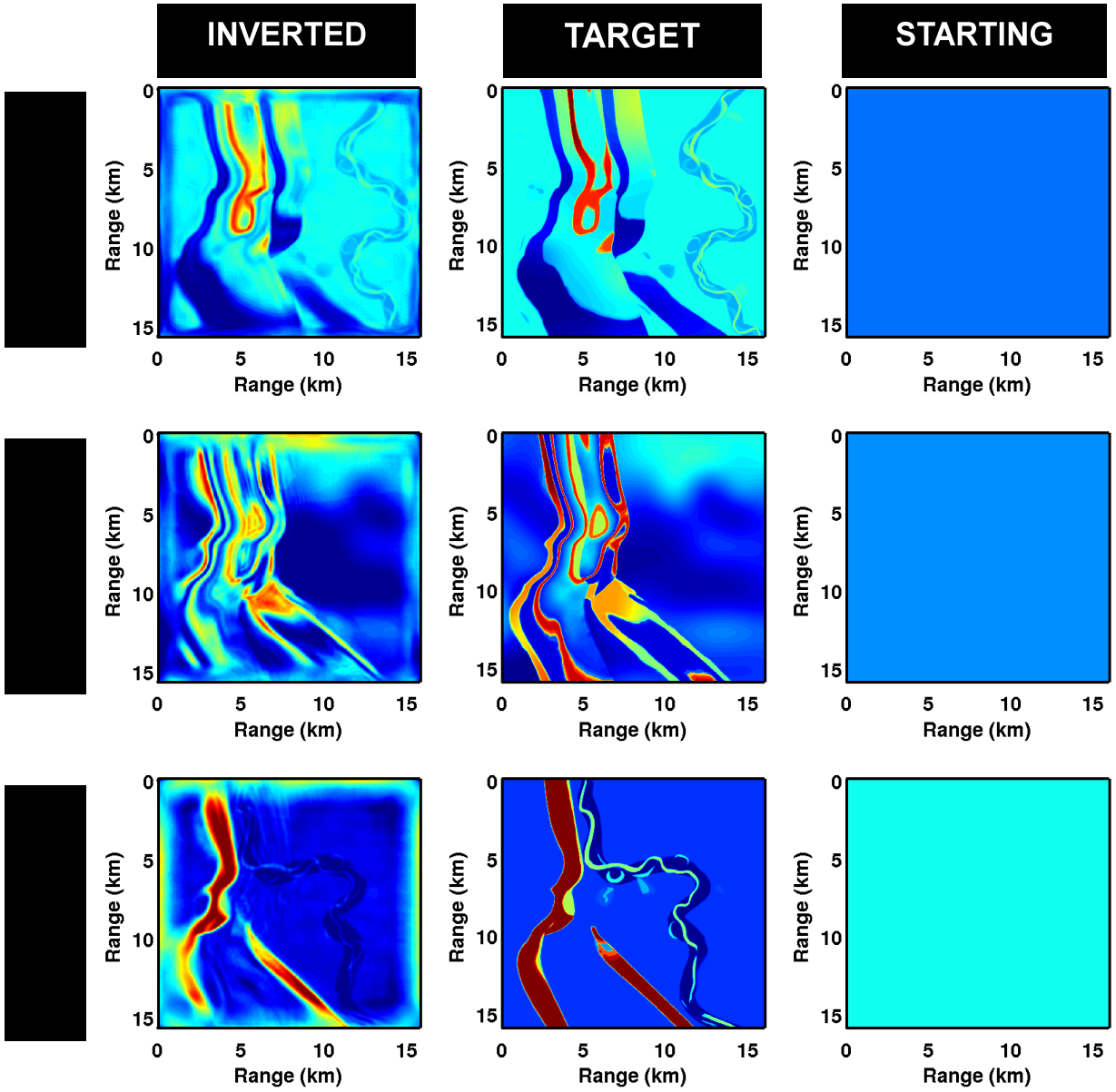


8 Hz

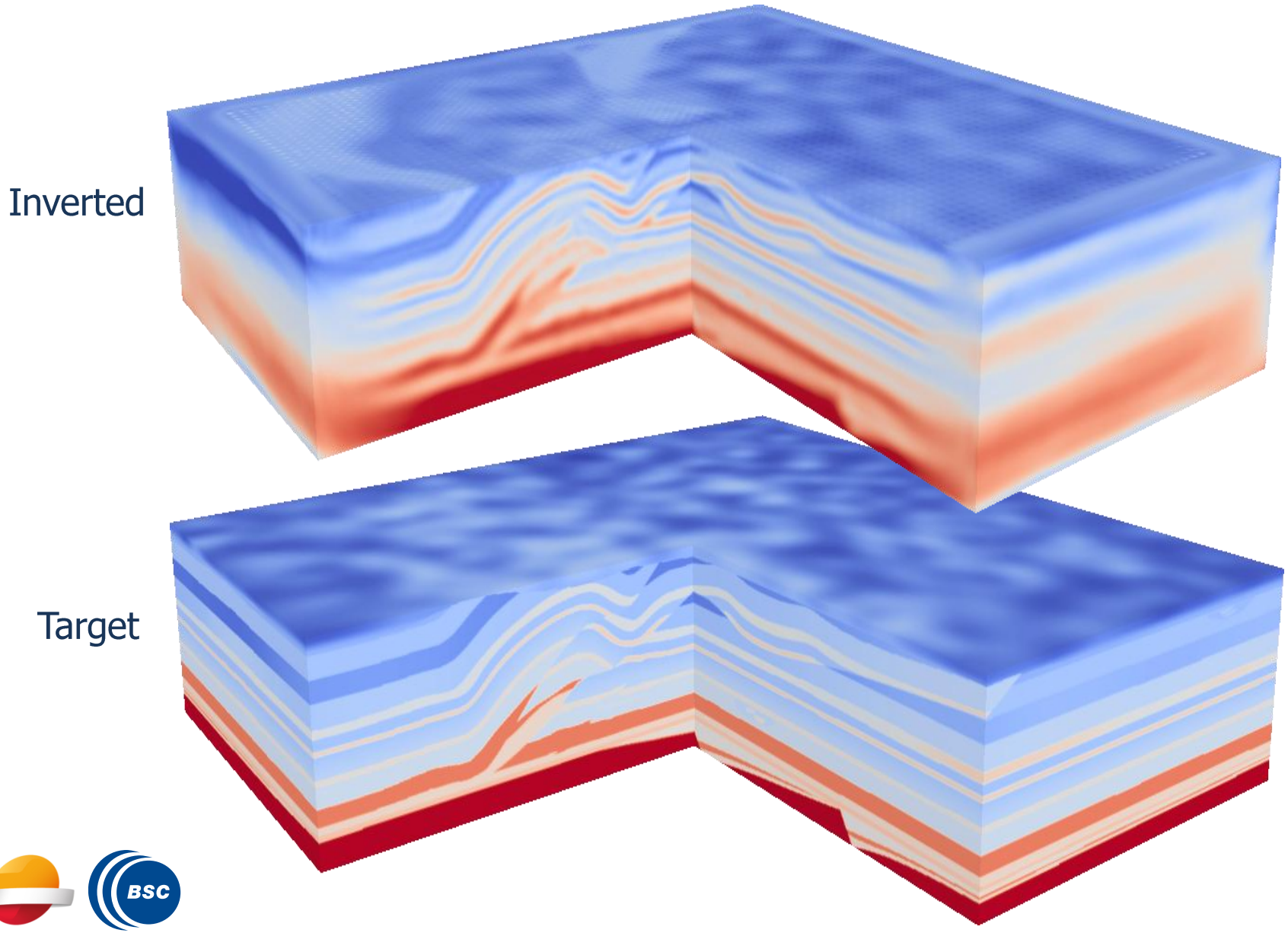


TARGET

Acoustic Full Waveform Inversion on BSIT



Acoustic Full Waveform Inversion on BSIT

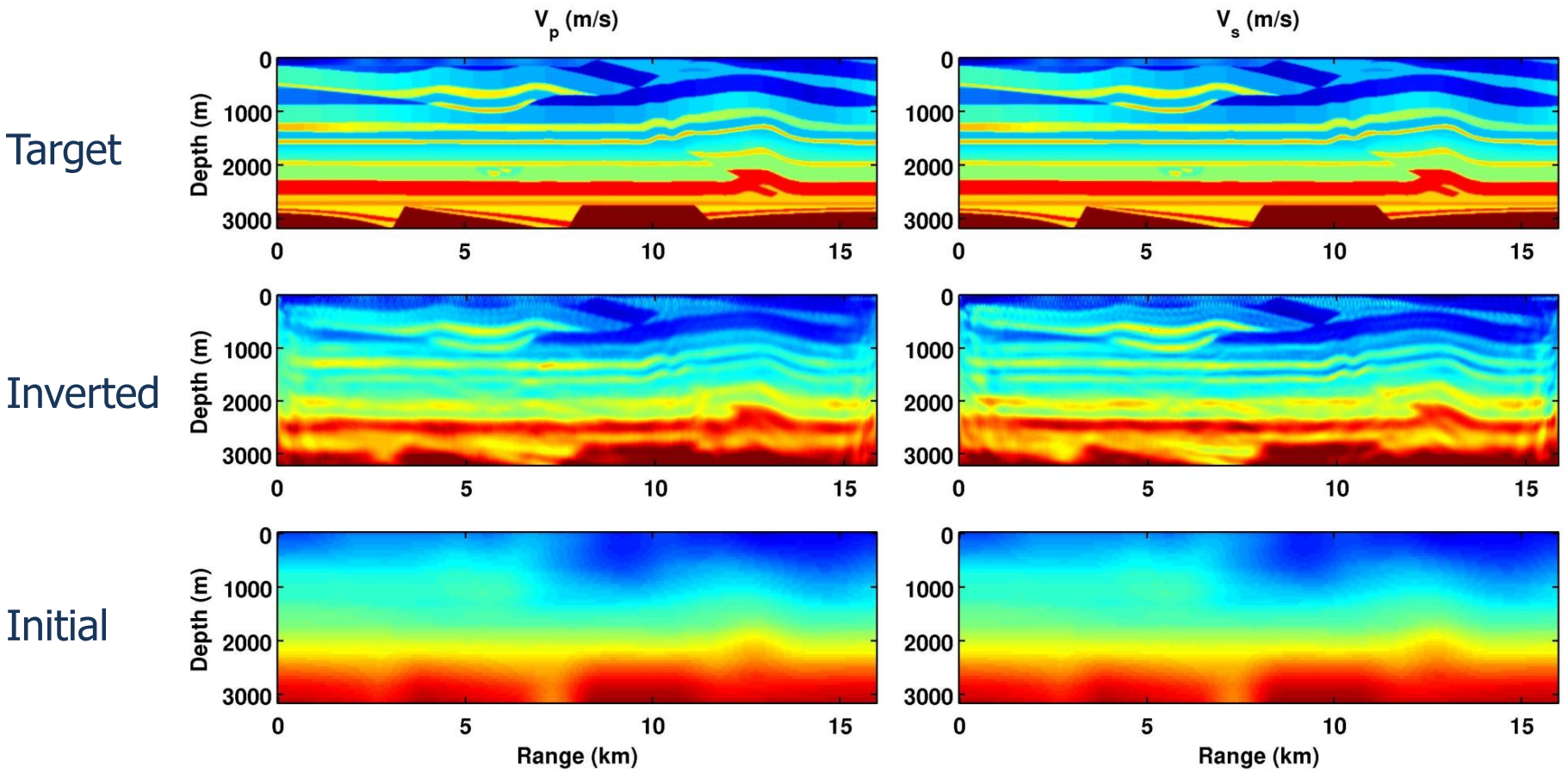


Elastic Full Waveform Inversion on BSIT

An Elastic Test Case

- Time-domain solution
- Multi-parameter inversion
- 2D elastic FWI
- 70 sources, variable number of receivers (2Km offset)
- 10 s of simulation (250 Gb of data)
- No supershots yet.
- 5 frequencies 10 iterations

Elastic Full Waveform Inversion on BSIT



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